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ON OF TYPES  
 INVESTIGATION ~~THE~~ RATE COEFFICIENT FOR VARIOUS ~~STRESS~~  
 OF ~~THE~~ STRESS STATE

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## ABSTRACT:

Tests on compression, tension, rolling, drawing, and pressing for various rates of deformation establish<sup>ed</sup> that the relation between stress and rate is unique for those forms of metal processing when the true equivalent stress is compared with the equivalent deformation.

The work of the Siberian Physico-Technical Institute (SPHTI) /1/ show<sup>ed</sup> that a unique rule stating the variation of stress with increase in rate can be established for tension, rolling, and pressing.

The aim of the investigations set forth below <sup>was</sup> to establish the possibility of extending the relation  $\sigma = \varphi(\dot{\epsilon})$ , obtained from tests on compression, to other pressure processes, (that is, drawing, tension, and cutting and also rolling and compression--the latter for the confirmation of results obtained in the SPHTI).

A description of the tests is given below.

## 1. TENSION

Round lead fracture specimens, prepared from previously forged lead, were subjected to tension. The dimensions of the specimens were maintained in accordance with <sup>standard</sup> specifications, with the diameter of the specimens, 20 mm and the gage length, 200 mm.

The fracture of the specimens was made on the Analer

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press with rates 0.01, 0.1, 1.0, and 10 mm/sec at a temperature of 20°C.

Figure 1 shows that fracture diagram, recorded on the drum of the machine.

Curves for true stress <sup>were</sup> ~~are~~ obtained by dividing the "flowing" force by the "flowing" area of the specimen, which is estimated from the fact that the volume of the metal must be constant during plastic deformation within the limits of uniform elongation; that is, up to the moment that a "waist" is formed.

As it is intended to compare the curves of true stress for extension, with those for compression and other pressure processes, it is necessary to solve the problem of equivalent deformations (strains).

In regard to this, we make use of Mesnager's /2/ proposal for the comparison of differential relative deformations during tension and compression, characterizing hardening; that is, by the equation:

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which after integration is brought to the final form:

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Figure 2 shows the curves of true stress, for extensions, as a function of the coefficient of deformation  $\frac{l}{l_0}$  (up to the moment of "waist" formation)

The values of true stress, corresponding to the various rates of deformation are given in Table 1.

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TABLE I	
Values of true stress in $\frac{\text{kg}}{\text{mm}^2}$ from extension tests	
on lead	20°C.
Rate of Deformation (1/sec.)	

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Figure 3 shows the dependence of true stress upon the rate of deformation, obtained earlier from compression tests on lead at 20°C./3/, at which each curve corresponds to an undetermined stage of deformation, and the corresponding coefficients of deformation. That is, in lieu of 10, 20, 30%, etc., (for specimens of an initial height of 20 mm), here are taken the corresponding coefficient deformation: 1.11, 1.25, 1.43, etc. In addition, the rate is plotted on the abscissae axis in terms of both percent/sec (%/sec) and also  $\text{sec}^{-1}$  (/sec) and the rate was calculated from the relation  $\dot{\epsilon} = \frac{\ln \epsilon}{t}$ .

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This diagram shows the values of true stress for various rates of extension, taken from Table I; the rate of deformation is calculated according to formula  $\dot{\epsilon} = \frac{\ln \epsilon}{t}$ .

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As we see, the values of true stress from extension tests, fall nicely into the previously obtained relation  $\sigma = \phi(\dot{\epsilon})$  for extension.

## 2. ROLLING

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Tests, performed by us earlier, /4/, as well as Pompa's and Weddige's tests were used.

In using these tests, performed by us under various conditions, we <sup>had</sup> ~~have~~ in mind the estimation of values of true stress and the rate of deformation during stress and to enter these values into the graphic relation  $\sigma = \phi(v)$  obtained earlier from compression tests. Since the rates of deformation during rolling vary very insignificantly, it <sup>was</sup> ~~is~~ possible to assume beforehand that as a result of the processing of the tested data, the dependence  $\sigma = \phi(v)$  is impossible to establish; it is possible only to establish how close the true stress during rolling (for any rate of deformation) satisfy the relation  $\sigma = \phi(v)$  for compression.

Tests with comparatively high rates of deformation were conducted by the author with Golubev and Orzechovskiy during rolling of sheets from ordinary carbon steels on a finishing stand of a three-high middle-grade, rolling mill-laut 850/500/850 Kuzmet <sup>Plant</sup> ~~Rolling~~; 80 rev/min of the rollers.

In order to exclude the influence of the spring of the rollers, the thickness of the rolled sheets <sup>was</sup> ~~is~~ measured with the help of a special measurer before and after operation.

The forces, reaching up to 2000 tons, <sup>were</sup> ~~is~~ measured by membrane-type hydraulic dynamometers.

At several points during rolling, the temperature <sup>was</sup> ~~is~~ simultaneously fixed with the help of a pyrometer.

The specific pressures during sheet rolling ~~as were~~ determined by dividing the measured forces by the area of the region of deformation.

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Some tested data on rolling is shown in Table II.

TABLE II

Tested data on the rolling of steel 3 in the Kuzmet <sup>Plant</sup> sheet mill (linear dimensions in mm)	
No. 11/11	
Initial thickness	$h_0$
Initial width	$b_0$
Thickness after operation	$h_1$
Width after operation	$b_1$
Decrement	$\Delta h$
Steel type:	
Temperature	(°C)
Forces P	(kg)
Specific pressure	
P.	$\frac{kg}{mm^2}$
Coefficient of elongation	$\lambda$
Rate of deformation	(1/sec.)
True stress	$\frac{kg}{mm^2}$

Now we shall cite the test data of Pompy and Waddige/5/.

Rolling took place in a 180 mm mill, whose rollers have a peripheral speed of 170 mm/sec; the rollers were polished from cast iron; the strips were heated before rolling in muffle furnaces.

The composition of the steel is shown in Table III.

TABLE III

Steel 1	c% etc.
	most figures

The data of some of Pompy's and Waddige's tests are shown in Table IV.

In order obtain the true stress from specific pressure in all above-cited cases of rolling, it <sup>was</sup> necessary to use one of the methods cited in the literature /6/.

We decided on the fully developed method of A. I. Tselikov,

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described in the literature. This method was used to calculate the true stress for all tests described in Tables 2 and 3. The final graphs of these tables show the figures for the true stress. The measure of deformation in agreement with the above-stated figures <sup>was</sup> taken to be the coefficient of deformation. The rate of deformation during rolling, expressed in  $\text{sec}^{-1}$ , are calculated by Pompu's and Weddige's equation/5/.

The values of the rate of deformation are shown in the next to the last <sup>lines in</sup> ~~graphs of~~ tables II and IV.

TABLE IV

Test Data on Rolling (Pompu and Weddige) (Linear Dimensions in mm)	
No. n/n.	
Initial thickness	$h_0$
Initial width	$b_0$
Thickness after operation	$h_1$
Width after operation	$b_1$
Decrement	$h$
Steel Type:	
Temperature	(°C)
Forces P	(kg)
Specific pressure	
p.	$\frac{\text{kg}}{\text{mm}^2}$
Coefficient of elongation	
Rate of Deformation	(1/sec.)
True stress	$\frac{\text{kg}_2}{\text{mm}^2}$

The values of true stress during rolling as a function ~~XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX~~ of the rate of deformation for certain cases are shown in Figures 4 and 5; they express the relation obtained by compression tests/3/, during which were compared:

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steel from KMZ tests with steel 3 and steels A and B from Pomph's and Weddige's tests with steels 3 and 10. It is evident from Figures 4 and 5 that the values of true stress in the majority of cases satisfy nicely the relation for compression.

### 3. PRESSING AND DRAWING

Tests were conducted on the Amsler press. Pressing (to reveal the influence of rate on stress) was conducted by a direct method; material used was lead and aluminum, of the same composition as the compression-test specimens. 1/4, 7/8. Ingots, preliminarily pressed ~~and of length~~ <sup>in length</sup> about 50 mm, and ~~diameter~~ <sup>in diameter</sup> 20 mm or 16 mm, were set into a container of inner diameter, 20 or 16 mm; the outlet in the die was 16 or 12 mm and the length of the cylindrical part of die A was 15 mm.

Several curves describing the pressure, as recorded automatically on the drum of the machine, are shown in Figure 6.

Pressing was performed at rates of motion of the press plates of 0.01, 0.1, 1, 10 mm/sec, and in all cases at a temperature of 20°C.

Specific pressures during pressing ~~are~~ <sup>were</sup> calculated by dividing the total force by the area of the press plates. In all, over 400 tests were made.

The drawing tests used lead and steel 3. The composition of steel 3 was as follows: C, 0.14; Mn, 0.42; Si, 0.26; S, 0.03; P, 0.04. A special clamping device was prepared during drawing. The drawing took place through a draw plate, fixed in the carriage of the Amsler press. The diameter of

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the gage of the bar was 10 mm for lead and 6 mm for steel;  
the diameter of the outlet of the draw plate was 8 mm for  
lead and 5 mm for steel; the angle assumed was  $40^{\circ}40'$  for  
lead, and for steel,  $5^{\circ}40'$ .

TABLE V

Tests on Pressing Lead and Aluminum Ingots (Linear Dimensions in mm)	
No. p/p	Steel
Diameter of Container D	1 mm
Diameter of Outlet d	P. 692
Metal	Keys 1 = Lead, 2 = aluminum
Average force P (kg)	
Specific pressure p (kg/mm <sup>2</sup> )	
Rate of Motion of press plates (mm/sec)	
Rate of Deformation (1/sec)	
True stress (kg/mm <sup>2</sup> )	

The rates of motion of clamps were the same as in the  
case of pressing, 0.01, 0.1, 1, and 10 mm/sec.

The effective active stress along the drawing axis  
was calculated by dividing the force by the outlet area of the  
section of the bar.

The forces during steel drawing were automatically  
recorded on the drum of the Amalier press. <sup>In</sup> the case of lead  
drawing, the forces were determined by a dynamometer inserted  
between the device for clamping the wire and the draw plate.

About 50 bars were drawn. Several tests are recorded  
in Table VI.



performed previously and converted to express deformation and rate of deformation as relative quantities, are given the values of true stress according to the data of Tables V and VI. As is evident from Figures 7, 8, and 9, the relation  $\sigma = Q(\dot{\epsilon})$  from drawing (little squares) and pressing (crosses) tests closely satisfied a similar relation from compression tests.

#### 4. CUTTING

The tests on cutting took place in the laboratory on an Amaler press and on shears of the 900-ton "1100" blooming of the Kuznets <sup>Plant</sup> ~~Works~~ /9/.

Lead bars were cut under laboratory conditions; the composition of lead <sup>was</sup> the same as that in the compression tests.

Special shears were constructed for the cutting.

The cutting force as a function of the depth of penetration of the shears into the metallic mass was recorded automatically on the drum of the machine (Figure 10).

The cutting took place at the rates (of motion of the lower carriage of the machine) 0.01, 0.1, 1.0, and 10 mm/sec.

The resistance to shears during cutting was obtained by dividing the "flowing" force of cutting into the "flowing" area of the remaining section of the cut bar.

It is necessary to keep in mind that the specific resistance to shears obtained in this manner is not the true (clean) stress of shears, because they include not only the final, but also the specific forces expended in overcoming friction and the deflection of the bar.

Special cutting tests with various ratios of section width to height  $b:h$  showed that the specific resistance of shears  $\tau'$  (for the same rate of deformation) depends upon the indicated ratio, (Figure 12). A more graphic presentation of the relation  $\tau = \varphi(b/h)$  is shown in Figure 11.

We see from Figure 11 that a decrease in the ratio  $\frac{b}{h}$  causes the values of  $\tau'$  asymptotically to approach a certain limiting value, which can be calculated for ratio  $\frac{b}{h} = 1$ .

Those values of  $\tau'$  not depending upon the ratio  $\frac{b}{h}$  can be accepted with sufficient accuracy as the true stress of shears  $\tau$ .

TABLE VII

Values of $\tau'$ for various conditions of cutting lead at 20°C.				
No. of Test	$b_0 \times b_0$ (mm)	Linear rate of cutting mm/sec.	Ratio $b_0$ :	V speed (1/sec)

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Insert figure

Further, the ratio of true stress of shears to rate of deformation was investigated in specimens of a square cross section. Figure 12 shows the curves  $\tau = \varphi(\dot{\epsilon})$  for various cutting rates.

The total number of tests was around 150. Table VII gives data on some cutting tests under laboratory conditions.

Guber-Mises' ratio  $\epsilon = \frac{\sigma}{\sigma_0}$  was used for calculating the normal stress.

Values of  $\sigma$  are in the denominators in Table VII. The rate of plastic deformation during cutting is calculated according to the equation  $\ln \frac{h_0}{h_1}$  when  $h_0$  and  $h_1$  are the initial thickness and the final "flowing" thickness of the bar.

In figure 13 the values of true stress during lead cutting are marked by crosses.

As is evident, the relation  $\sigma = \sigma_0 \epsilon^n$  for cutting agrees closely with a similar relation as obtained earlier from compression tests.

A comparison of the tests can show that the relation between stress and rate of plastic deformation is unique for various forms of metal processing.

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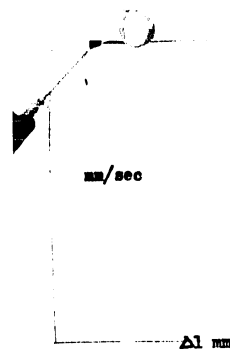


Figure 1  
Indicator curves  
for Lead at 20°C.

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FIGURES --1  
kg/mm<sup>2</sup>  
mm/sec

Figure 2  
Curves of Nominal and  
True stress

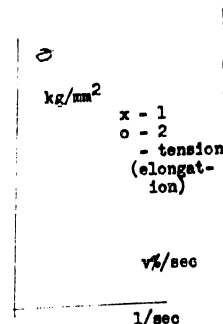


Figure 3  
 $\sigma = \phi(\epsilon)$  for  
tension and com-  
pression, lead at  
20°C.  
1- for coefficient of de-  
formation 1.10  
2- for coefficient of de-  
formation 1.26

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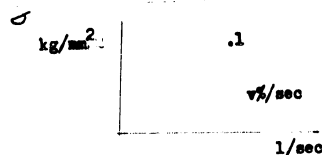


Figure 4  
 $\sigma = \phi(\epsilon)$  for compression and rolling,  
steel 3 at 1000°C.  
1 - Points referring to rolling

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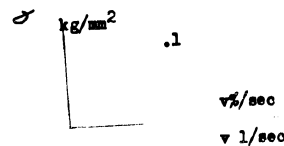


Figure 5  
 $\sigma = \phi(\epsilon)$  for compression and rolling,  
steel 40 KhA at 1000°C.  
1 - Points referring to rolling

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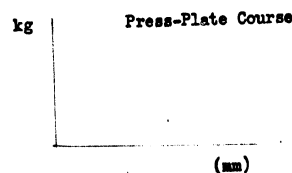


Figure 6  
Indicator Diagrams for the Compression  
of lead at 20°C. D = 20mm; d = 16mm;  
v = 1mm/sec

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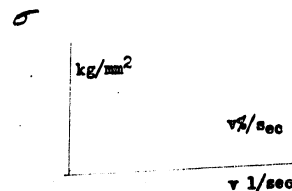


Figure 7  
 $\sigma = \phi(\epsilon)$  for aluminum at 20°C.

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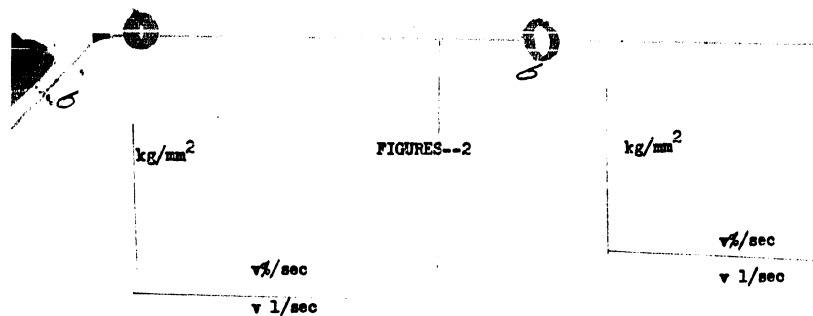


Figure 8 For lead at 20°C.  
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Figure 9 for Steel 3 at 20°C.  
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kg mm/sec  
Depth of Penetration of  
Shears (mm)

$\tau$  kg/mm<sup>2</sup>

$\frac{1}{h}$

Figure 10  
Cutting force as a function of Depth of  
Penetration of Shear; Lead at 20°C  
In parentheses: 1st figure: Width  
2nd figure: height of the cut cross sec-  
tion.

Figure 11  
The Dependence of the Resistance of Lead  
During Cutting upon the Ratio of Width  
of Cross Section to its Depth  
(Lead, 20°C,  $v = 1 \text{ mm/sec}$ )

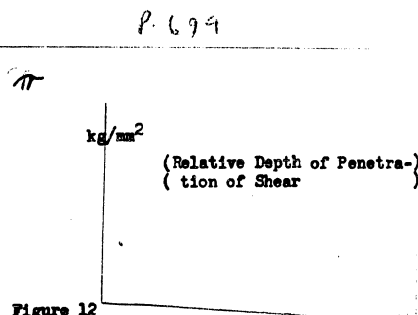


Figure 12  
Dependence of the Specific Resistance of  
Lead During Cutting upon the Relative  
Penetration of the Shear into metals  
(Lead, 20°C).

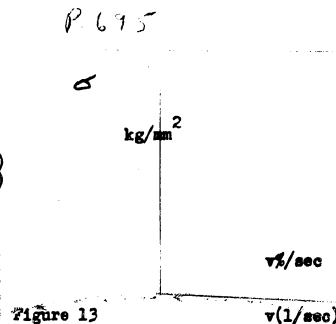


Figure 13  
 $\sigma = \frac{F}{A}$  for Lead at 20°C.

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